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Examination of Ice-Crystals by X-Rays

By

Usaburo Yoshida and **Shogo Tsuboi**

(Received May 13, 1929)

Abstract

The orientation of ice-crystals obtained under various conditions was examined by means of X-rays, and it was found that all directions parallel to the basal plane of the hexagonal crystal of ice are equally suited for its growth.

For the determination of the orientation of the crystallographic axes of ice, the optical method, in which a polarized light is used, is only effective for the direction of the principal axis of the hexagonal ice-crystal, and has no bearing on the other crystallographic directions. With X-rays, however, not only is this defect of the optical method remedied, but some-times even the arrangement of the microcrystals oriented in some regular manner can be determined. Thus the writers have examined roentgenographically some specimens of ice obtained under various conditions. The method and the results obtained are described below.

In order to take a Laue-photograph with ice, we must keep the specimen frozen throughout the whole exposure of the photographic plate. For this purpose a simple apparatus as shown in Fig. 1 was employed. In this figure C is a copper rod, and the specimen to be examined is inserted in a small vertical hole A in the upper part of the rod C. The small horizontal hole B passing through the upper part of the rod C is a slit for the X-rays. The X-rays starting from the molybdenum target of a Coolidge tube illuminate the specimen of ice in the hole A, after passing through the slits S and B; and the pattern of the diffracted X-rays is impressed on the photographic plate P standing perpendicularly to the incident X-ray beam. The specimen of ice is kept frozen, in winter, by dipping the lower part of the copper rod C in a suitable freezing mixture.

The orientation of the crystallographic axes of the ice-crystal was determined by treating the Laue-spots, taken with the specimen to be tested, with the globe and the spherical scale first devised by one[1] of the writers.

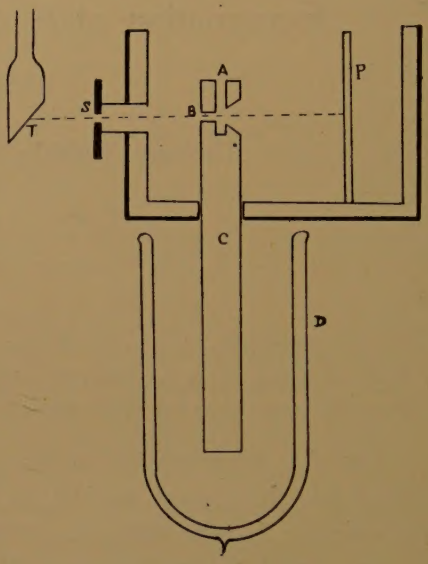


Fig. 1

First the writers examined the orientation of the crystallographic axes of ice, which had been frozen on the surface of calm water by being exposed to the cold air during a fine night in winter. The Laue-photograph taken with a piece of such ice consists usually of one set of Laue-spots belonging to a single crystal of ice, as seen in Fig. 1, Plate I. This fact indicates that the ice obtained under such circumstances is composed of single crystals of considerable size. The orientation of the crystallographic axes of seven different pieces of ice, obtained on different days in different localities, is shown in Fig. 2 in a stereographic projection. In this figure the direction of the normal to the flat surface of ice, that is the direction of the surface normal of water is represented by a dot in reference to the directions of the crystallographic axes oool, $10\bar{1}0$ and $11\bar{2}0$ of the hexagonal crystal of ice. As is seen in this figure, all the dots are crowded near the direction of the principal axis oool. This fact shows that under the circumstances mentioned above, the water freezes in such a manner, that the basal plane of the hexagonal crystal of ice

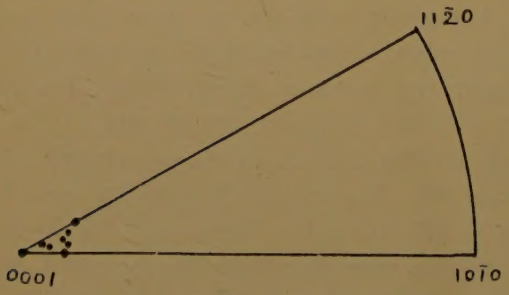


Fig. 2

1 U. Yoshida; Japanese J. Phys., 4, 133 (1927)

produced is nearly parallel to the surface of the calm water.

If we consider that the ice on the surface of such calm water grows horizontally, from a certain nucleus, along the surface of the water, the horizontal orientation of the basal plane of the hexagonal crystal of ice seems to be caused by the fact that the growth of the ice crystal is easier in the directions parallel to the basal plane of the hexagonal ice crystal.

The same phenomenon was also observed in ice columns in the ground. Usually an ice column in the ground takes a long prismatic form, each prism consisting of several smaller prisms of single crystals of ice of about 0.5 mm. in diameter. The orientation of the crystallographic axes of these single crystals of ice were determined by taking their Laue-photographs, and the direction of the axis of the prisms of such single crystals is represented, in a stereographic projection, by the position of the small circles in Fig. 3, refering to the direction of the crystallographic axes. Here again we can see that the direction of the growth of the ice crystal is perpendicular to that of the principal axis, namely parallel to some direction in the basal plane of the hexagonal crystal.

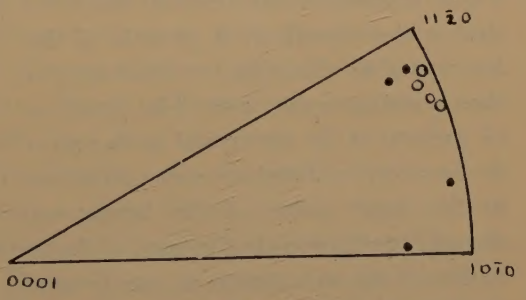


Fig. 3

Sometimes it was very difficult to split a prism of an ice column in the ground into component prisms of single crystals. In such a case a Laue-photograph was taken with such a prism as a whole. The resulting Laue-spots, consisting of two or more sets of the Laue- spots belonging to two or more single crystals of ice in different orientations of their crystallographic axes, were classified into two or more sets by trial with the spherical scale and the globe previously described; and the orientations of the crystallographic axes of the separate crystals corresponding to the separate sets of the Laue-spots were determined at the same time. Fig. 2 in Plate I is shown as an example of this. It was found, in the manner stated above, that the Laue-spots in this figure were due to two single crystals of different orientations. The result of classification of these Laue-spots into

two sets due to two separate single crystals is shown in Fig. 4, where all the small circles are due to a single crystal and all the dots are due to another single crystal of different orientation. The big dot in that figure indicates the position of the impression of the direct X-ray beam, and the arrow represents the direction parallel to that of the axis of the prism of the ice column in the ground.

The growth of ice is also slow in the course of the development of an icicle. In the portion near its upper root it is formed of many small crystals of ice, and at its lower end it consists usually of a rather slender single crystal of ice. The orientation of the crystallographic axes of the ice crystal was determined in four such slender single crystals forming the lower ends of four different icicles. The dot in Fig. 3 represents the vertical direction, that is the direction of growth of the ice crystal in this case, in reference to the crystallographic axes. The direction of growth of the ice crystal is also seen to be nearly parallel to some direction in the basal plane of the hexagonal crystal, as was seen in the case of the ice on the calm water surface and in that of the ice column in the ground. The distribution of dots and small circles in Figs. 2 and 3 shows us that all directions parallel to the basal plane of the hexagonal crystal of ice are equally suited for the growth of ice. The Laue-photograph taken with a piece of ice at the lower slender end of an icicle is shown in Fig. 3, Plate I.

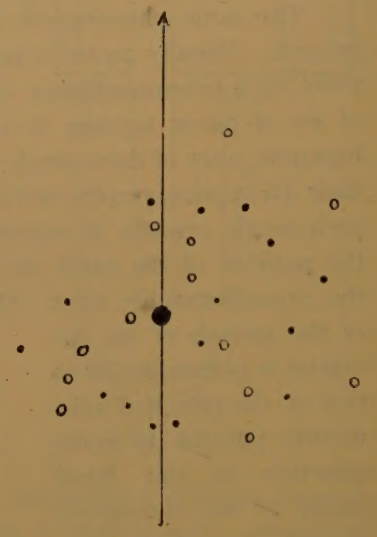


Fig. 4

When ice is formed by rapid cooling, for example as in the case of artificial ice, no such regular orientation of the ice crystal as that stated before could be detected. Artificial ice is composed of many long cylindrical ice-crystals; and the direction of the axes of such cylinders may be looked for as the direction of growth of the ice crystal. The results of experiment on several such cylindrical pieces of ice show that there is no regularity in the orientation of the crystallographic axes, as is seen in Fig. 5. In this figure the dot represents the direction of the axis of the cylinder of ice in reference to the

crystallographic axes. The ice formed by the condensation of water vapour in the air on the surface of a super-cooled metal consists of an assemblage of small ice crystals. The X-ray examination shows that the orientation of such small crystals is entirely at random.

When a drop of water is brought into contact with a piece of a single crystal of ice, whose temperature is a little lower than o°C, then the drop of water solidifies slowly. The orientation of the crystallographic axes of ice thus newly formed was confirmed, by the X-rays, to be entirely the same as that of the mother crystal of ice. However, when the temperature of the mother crystal of ice, on which the drop of water added solidifies, is much lower than o°C, then the drop of water freezes rapidly. The ice thus formed suddenly from the drop of water was ascertained, by means of X-rays, to be composed of many small crystals in a random orientation. Fig. 4 in Plate I is a long slit Laue-photograph[1] taken with a thin and long specimen of ice, which is composed mostly of a single crystal of ice and of a small piece obtained by sudden cooling from a drop of water added to the upper end of the single ice-crystal. The presence of many spots distributed rather irregularly in the upper part of the figure indicates that the ice thus formed by sudden cooling from a drop of water is an aggregate of many small crystals in an irregular orientation.

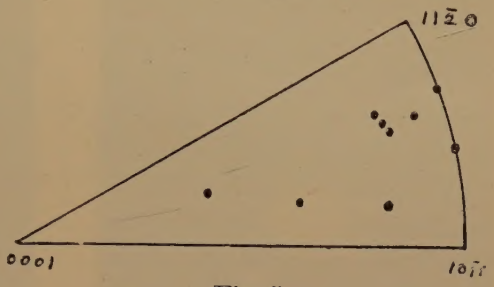


Fig. 5

1 U. Yoshida and K. Tanaka : Nature, **118**, 912 (1926)

Plate I

Fig. 1

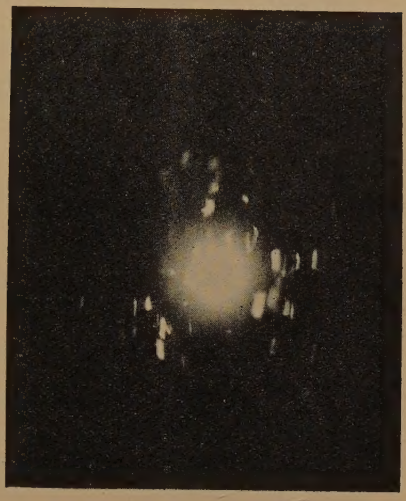


Fig. 2

Fig. 3

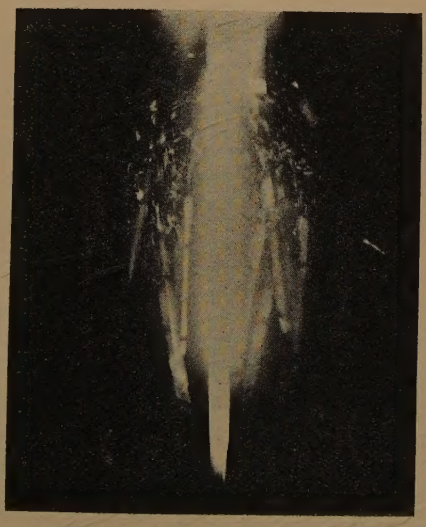


Fig. 4

On the Fibrous Structure in Metals deposited through Difference in Electrolytic Solutional Pressures,

Part II

By

Shogo Tsuboi

(Received June 3, 1929)

Abstract

The arrangement of micro-crystals in the thin plates of metallic lead and cadmium, which were deposited out in some salt solutions by a piece of zinc being put into the solutions, was examined. The majority of the micro-crystals in the lead deposits have one of the (111) planes of the cubic crystal nearly parallel to the flat surfaces of the deposits. In the case of cadmium deposits, the (0001) plane of the hexagonal crystal is situated nearly parallel to the flat surfaces of the specimens.

The arrangement of micro-crystals in metallic silver, which was deposited out in a solution of silver nitrate due to the presence of a piece of copper in it, has already been examined by the writer.[1] In the present experiment, the crystalline structure of lead and cadmium deposits, which were separated out in solutions of lead acetate and cadmium sulphate respectively due to the presence of a small piece of zinc, was examined as in the previous experiment.

Lead

Small zinc plates were suspended in a 2% and in a 5% solution of lead acetate, in order to obtain the well known deposits named "lead tree." These deposits, which are of a spongy structure, consist of several very thin plates with metallic lustre. The experiment were carried on these thin plates. In a micro-photograph taken with one of

1 These Memoirs, **11**, 271 (1928)

these thin plates, we can see the dendritic structure of the deposits, as in Fig. 1, Plate I.

The direction of growth of a specimen in a dendritic form, which was obtained in a 5% solution, was set vertically, and a horizontal beam of the X-rays from a molybdenum target was projected normally to the flat surface of the specimen. Although most of the Laue-photographs thus obtained show a fibrous structure in the deposits, as is seen in Fig. 3, Plate I, there are some specimens which give X-ray diffraction patterns of ordinary Laue-spots, as is seen in Fig. 2, Plate I. The analysis of the distribution of the Laue-spots in that figure, by the aid of the globe and the spherical scale devised by Prof. U. Yoshida[1], proves that the distribution of the Laue-spots is due to two crystals at different orientations. The Laue-spots in Fig. 2, Plate I are represented by dots and small circles in Fig. 1, where all the dots correspond to one lead crystal at a certain orientation, and all the small circles correspond to the other lead crystal at a different orientation. It is also found, by the analysis stated above, that one of the [111] axes of the cubic crystal of lead is common to the two crystals under consideration, and that this common axis [111] is perpendicular to the flat surface of the specimen. The crystallographic direction [211], which is at right angles to the common [111] axis under consideration, is shown in Fig. 1 by the straight lines AA′ or BB′ according as the crystal belongs to that corresponding to the dots or the small circles respectively. Consequently the orientation of one crystal can be obtained from the other by rotating it through an angle of about 27° around the common axis [111]. In

Fig. 1

1 Japanese J. Phys. **4**, 133 (1927)

Fig. 2 the direction of growth and the surface normal of the specimen are represented in stereographic projection, by taking the [100], [110] and [111] axes of the cubic crystal as the reference axes. The dot and the small circle in this figure correspond respectively to those in Fig. 1.

By comparing the two photographs in Figs. 2 and 3 in Plate I we can detect a close similarity between the distribution of the Laue-spots in Fig. 2 and that of the radiating bands in Fig. 3. This leads us to the supposition that the fibrous structure corresponding to Fig. 3, Plate I, may be due to the rotation of the micro-crystals within a certain small angle from their ideal orientation which corresponds to the distribution of the Laue-spots in Fig. 1. In this way the writer assumed with success that the radiating bands in Fig. 3, Plate I were due to two fibrous arrangements, the one consisting of the micro-crystals rotated around the direction parallel to AA′ in Fig. 1, within a certain small angle from the ideal orientation which corresponds to the dots in the same figure, and the other consisting of the micro-crystals rotated around the direction parallel to BB′ in Fig. 1, within a certain small angle from the ideal orientation which corresponds to the small circles in that figure. As to the amount of rotation of the micro-crystals from their respective ideal orientations, it was found, by tracing the radiating bands in Figs. 3 of Plate I on the globe and the spherical scale mentioned before, that the rotation within an angular interval of $\pm 5^\circ$ was enough for both fibrous arrangements. The radiating bands represented in Fig. 3, which are provided with the K_α spectra of molybdenum, are obtained under the above consideration. A fair agreement of its general aspect with Fig. 3, Plate I seems to show reversely the correctness of the previous supposition. Thus, if we disregard the small rotation of the micro-crystals around the ideal orientation, we may conclude that one of the atomic planes (111) of the micro-crystals in the lead deposits lies parallel to the flat surface of the specimen, and that the direction of growth

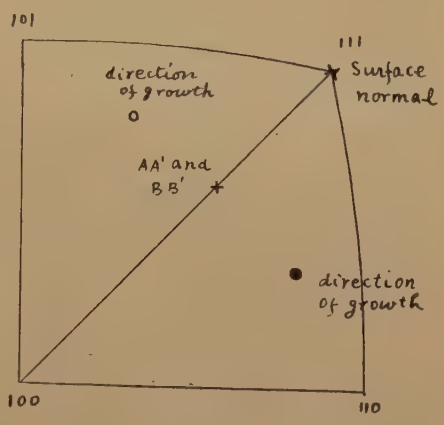


Fig. 2

in the same atomic plane is different for every specimen.

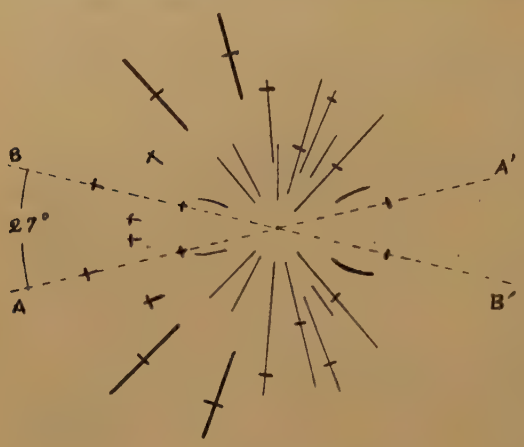


Fig. 3

On the other hand, a piece of the lead deposits reflects light in many different directions. Although the reflected light is a little diffused, due to a small scattering of the orientation of the micro-crystals as stated before, the direction of the light reflected with maximum intensity, due to the light incident on the surface of the specimen at definite direction could be determined easily with a simple goniometer. In Fig. 4 the direction of the normals to the reflecting planes, thus determined on the same specimen as that of Fig. 3, Plate I, is represented in a stereographic projection, where the dots and the small circles correspond respectively to the light reflecting surfaces on the incident and the emergent sides of the X-rays in photographing Fig. 3, Plate I. The pole in Fig. 4 coincides with the direction of the normal to the flat surface of the specimen, that is with one of the crystallographic axes [111]. The broken lines AA′ and BB′ in the same figure have the same meaning as in the case of Figs. 1 and 3. The distribution of the dots in that figure thus represents the angular relation between the crystal faces of the cubic crystal of lead at the side of the specimen on which the X-rays were incident, and the distribu-

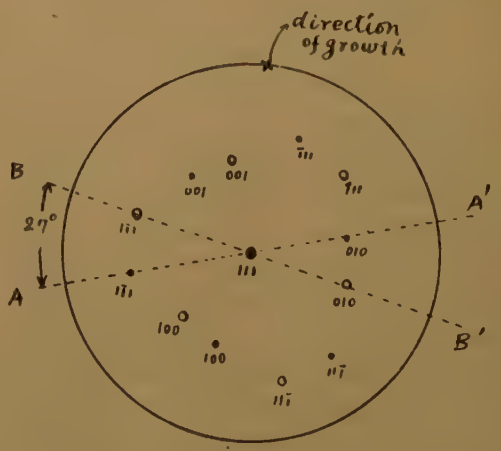


Fig. 4

tion of the small circles shows the angular relation between the crystal faces of the lead crystal at the side of the specimen on which the X-rays were emergent. The angular separation between the two orientations of the crystals on both sides of the flat specimen is equal to the angle between AA′ and BB′ and is about 27°. Consequently the orientations of the lead crystals in the specimen, which are obtained by the method of light reflection are in fine accordance with those found by means of X-rays in the case of Fig. 2, Plate I, that is with the ideal orientation of the micro-crystals of lead in the specimen.

This coincidence indicates that the (111) and the (100) planes of the lead crystals represented in Fig. 4 are really developed as the exterior surfaces of the micro-crystals. This point was also confirmed by microscopic observation, and the outward form of each micro-crystal seems to be such as represented in Fig. 5.

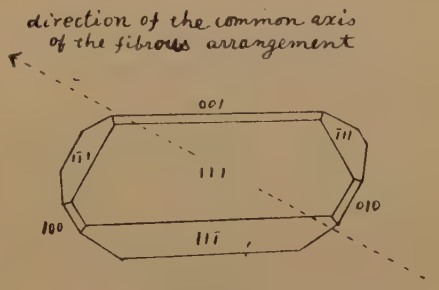


Fig. 5

A Laue-photograph taken with the specimen obtained in a 2% solution is shown in Fig. 4, Plate I. The identity of the essential feature of this photograph with that of Fig. 3, Plate I indicates that the concentration of the solution has no appreciable influence on the crystalline structure of the deposits.

Cadmium

In a spongy mass of cadmium, separated out in a solution of cadmium sulphate by putting a piece of zinc into it, there are several thin plates with metallic lustre. The specimens of such thin plates obtained in a 1% and in a 3% solution of cadmium sulphate were examined in the present experiment.

Under microscopic observation, the specimen shows a dendritic structure, the fine branches of which make an angle of about 60° to each other, as is seen in Fig. 5, Plate I.

The direction of growth of the specimen, deposited in a 1% solution, was set vertically, and a horizontal beam of X-rays from a molybdenum target was made to strike the specimen normally to its flat surface. A Laue-photograph, thus obtained, is reproduced in Fig. 6,

Plate I. The diffraction pattern in this figure consists of many Laue-spots, which are elongated only a little in radial directions. This fact indicates that the specimen can be looked upon as being nearly composed of a few single crystals. The analysis of the Laue-spots, by the aid of the globe and the spherical scale, shows that the specimen consists of two hexagonal crystals of cadmium in different orientations, as was observed in the lead deposits.

Fig. 6

Fig. 6 is a sketch of Fig. 6, Plate I, where the dots and the small circles represent the two sets of Laue-spots belonging respectively to the two crystals in different orientations. It became clear from the analysis that, for the two crystals in different orientation, the [0001] axis of the hexagonal crystal of cadmium is parallel to the normal to the flat surface of the deposit, and that the direction of growth is nearly parallel to the $[21\bar{3}0]$ axis for the two crystals. In Fig. 6 the broken lines AA′ and BB′ are in the direction of the $[\bar{1}100]$ axes of the two crystals in different orientations respectively, which correspond to the dots and the small circles. Thus the orientation of one crystal is obtained from the other by rotating it through an angle of about 28° around the [0001] axis, which is

Fig. 7

common to two crystals.

The results obtained with the light reflection method, which was used in the case of lead, are shown in Fig. 7 by stereographic projection. Here the dots represent fhe direction of the normals to the reflecting planes on the incident side of the specimen for the x-rays, and the small circles represent those on the emergent side. Thus, as in the case of the lead deposit, the crystallograhphic orientation is different for the crystals on the two flat surfaces of the deposits. The [0001] axis is common to the two orientation, and the $[\bar{1}100]$ axes of these two orientations make an angle of about 28° to each other. This is in fine accordance with the results obtainded with the X-rays.

Similar experiments made on different specimens obtained under the same conditions, show that the angle between the $[\bar{1}100]$ axes of the crystals in two layers take various values between 22° and 28°.

As to the crystal faces developed actually as the outward form of the cadmium crystal, the results obtained above indicate that they are (0001) and $(10\bar{1}1)$ faces.

Experiments were also carried on specimens deposited out in a 3% solution, but no appreciable influence of the difference of concentration could be detected.

In conclusion, the writer wishes to express his sincere thanks to Professor U. Yoshida of Kyoto Imperial University for his kind guidance and encouragement during the research.

Shiga Normal School,
May 8, 1929.

Plate I

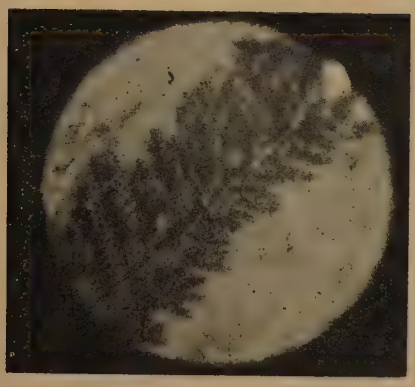


Fig. 1 (magnification 100)

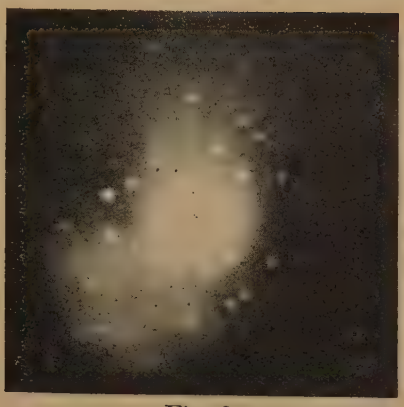


Fig. 2

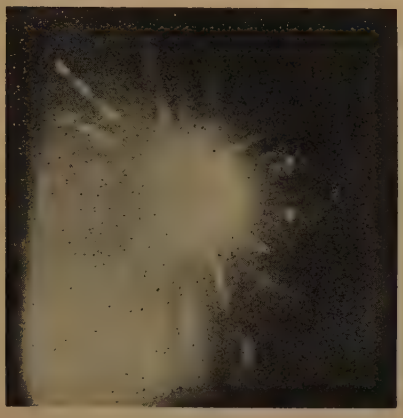


Fig. 3

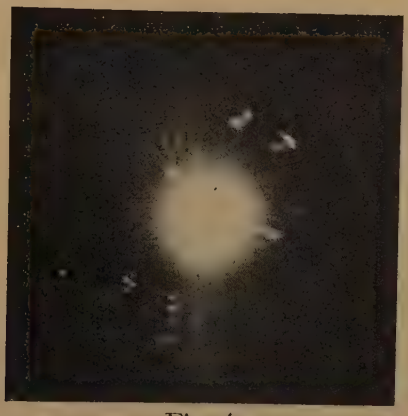


Fig. 4

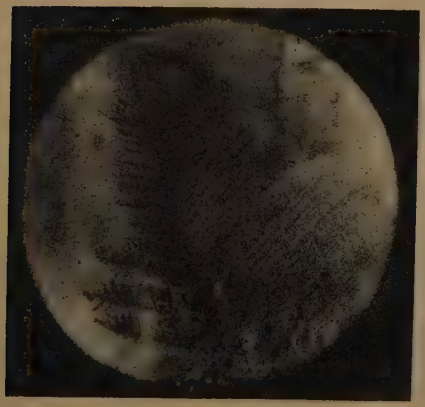


Fig 5. (magnification 100)

Fig. 6

"The Reversal-Like Phenomena" of the Discharge-Figures impressed on Photographic Plates

By

Tatsumi Terada

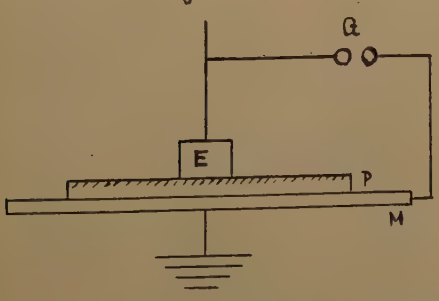
(Received June 3, 1929)

Abstract

The "reversal-like phenomena" of the discharge-figures on photographic plates, which are produced by illuminating the plate with a spark light simultaneously with the impression of the discharge-figure, are examined in the present experiment. The discharge-figures giving rise to the phenomenon are similar to dust-figures, and it seems to the writer that the ions produced on the sensitive film of the plate have an important bearing on this phenomenon.

In the experimental arrangement shown in Fig. 1, P is a photographic plate which is covered beneath with an earthed metal plate M, E an electrode laid on the sensitive film of the photographic plate, and G is a spark gap inserted between the electrode E and the earthed metal plate M. When a negative or a positive electric impulse of sufficient amplitude reaches the electrode E and the spark gap G, and if the photographic impression of the discharge-figure takes place at the same time as the spark at the gap G, an interesting phenomenon occurs in the negative and positive discharge-figures, in the region illuminated by the spark light. In the negative figure an enveloping margin appears at the ends of the regular negative branches as shown in Fig. 1, Plate I; and in the positive figure, each branch is enveloped

Fig. 1



separately with a somewhat diffuse margin of stronger intensity as shown in Fig. 2, Plate I. These interesting phenomena occur also in the secondary and in the tertiary discharge-figures as in the primary one, when the fogging of the sensitive film by the spark light takes place at the same time as the photographic impression of the discharge figure. The writer will call this phenomenon "the reversal-like phenomenon" as in his former paper[1].

Prof. U. Yoshida and Mr. J. Tsutsumi[2] have made public recently an important work on this phenomenon. According to them the wave-lengths of the illuminating light, which was effective in producing this phenomenon, were shorter than about 420 $\mu\mu$; and from this fact they suggested that the reversal-like phenomenon was due to the photo-electric effect of the fogging light upon the photographic plate which was subjected to a strong electric field. In the present experiment, this point is further examined from different sides.

Lichtenberg devised an ingenious and easy way to see the distribution of electricity in the brush discharge, by using electroscopic powders. The discharge electrode in Fig. 1 is now placed on a dry glass plate P which is laid on an earthed metal plate M, and a mixture of flower of sulphur and red lead is sifted, through a piece of cloth, over the glass plate. When mutual friction takes place between these powders, each particle become electrified: the sulphur negatively and the red lead positively. Thus if an electric impulse of sufficient amplitude reaches the electrode E, a dust-figure will be formed on the glass plate. Fig. 3 in Plate I is a photograph of the actual figure obtained by applying a negative electric impulse to the electrode E, and Fig. 4 in Plate I is that obtained by applying a positive electric impulse, without causing any spark to pass across the spark gap G. The effect of the occurrence of a spark at the spark gap G simultaneously with the brush discharge at the electrode E is also examined; but, so far, the essential features of the dust-figures shown in Figs. 3 and 4 in Plate I seem to suffer no remarkable influence.

If we compare the dust-figures with fogged discharge-figures on photographic plates, a close resemblance will be detected respectively among the negative and among the positive figures. As the dust figures are caused by the presence of the charged particles, this close

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1 T. Terada; These Memoirs, **11**, 355 (1928)

2 U. Yoshida and J. Tsutsumi; These Memoirs, **11**, 267 (1928)

resemblance seems to suggest that the reversal-like phenomenon may be caused by the presence of charged particles or ions on the photographic plate, which are produced directly or indirectly by the fogging spark light. If so, the reversal-like phenomenon of the discharge figures on the photographic plates will also be given rise to at least in some degree, without any fogging spark, by putting many ions, in a different manner, on the photographic plate just before or simultaneously with the occurrence of the brush discharge. With this idea, the writer has made the following experiment:

When the sensitive film of a photographic plate, which has been thoroughly dried, is rubbed with well-dried cat's fur, it becomes charged with negative electricity as is proved by an electroscope. The photographic plate thus electrified negatively was used instead of an ordinary uncharged plate; and when, without any fogging spark, a negative discharge figure was impressed on it, the reversal-like phenomenon peculiar to the negative figure occurred in a weak degree. A somewhat diffuse and weak enveloping margin appeared now in the portion just outside the discharge figure, leaving a nearly unaffected dark and narrow portion between the enveloping margin and the end of the regular negative branches just as in Fig. 1, Plate I. Next, when the negative discharge figure was impressed on a photographic plate, the sensitive film of which had been electrified positively by rubbing it with a well dried piece of soft leather, the same enveloping margin as above could also be detected. Similar experiments were also carried out with the positive discharge figure, and the expected phenomenon could be observed also at the portion near the end of every branch. From these results it may be concluded that the presence of the negative or the positive ions on the surface of the plate has an important bearing in producing the phenomena under consideration. It is regretable that the reversal-like phenomena were too weak, in this case, to be reproduced clearly here. The weakness of the phenomena was probably due to the fact that the number of the ions present on the sensitive film was too small to cause the phenomena strongly. Thus with a view of obtaining similar results clearly, another experiment was undertaken.

The arrangement used is schematically illustrated in Fig. 2. In this figure E, P and M have the same meaning as in Fig. 1. N is a hundle of about one hundred needles, and it is placed at a height of about 9 cms. above a dried photographic plate.

When one of the terminals of a small induction coil is connected to the needle-bundle N and the other to earth, the brush discharges at the lower end of the needle-bundle will shower many ions on the surface of the photographic plate. After the photographic plate was thus charged negatively or positively for a few seconds in each experiment, the negative or positive discharge figure was impressed on it. From the photographs thus obtained the writer could again observe that the reversal-like phenomena appeared in the negative as well as in the positive figure, though in a weak degree. Thus it seems to be very probable that the reversal-like phenomena, which are produced by fogging the plate with spark light simultaneously with the impression of the discharge figure, are due to the presence of many ions on the photographic plate, such as that of the charged powders in the case of dust-figures. If so, a close inspection of the distribution of the positive and negative powders in the dust figure will assist in the solution of the phenomena under consideration.

Fig. 2

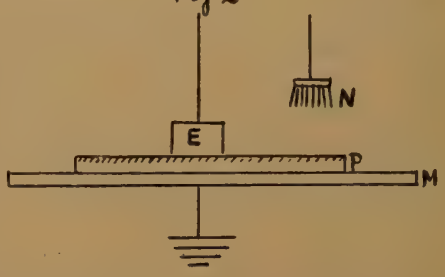


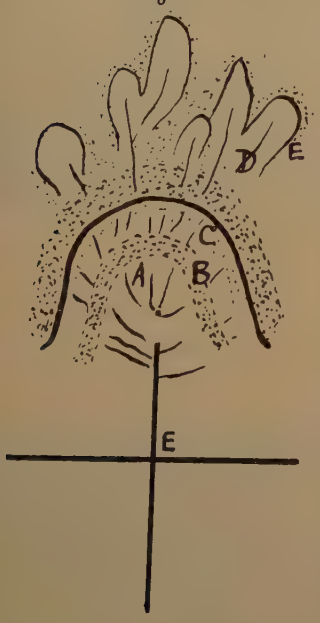
Fig. 3

Fig. 3 is a sketch of a part of the negative dust figure. Here A represents hollow branching streaks occurring on a somewhat yellowish background, B a reddish enveloping margin produced by the massing of the grains of red lead, and C a somewhat yellowish outer margin. There is nothing in the portion between the reddish zone B and the somewhat yellowish outer zone C. From the distribution of the powders it seems probable that the negative charge would be in excess at the end of the hollow branching streaks A. Consequently the grains of red lead, which were charged positively or would be so, would be attracted toward the ends of the hollow streaks; while the grains of sulphur, which were charged negatively or would be so by being rubbed against the

grains of red lead, would be repelled from the ends of the hollow streaks. The electric field in the portion between B and C will be thus very much weakened by such separation of the charged particles.

Fig. 4 is the sketch of a part of the positive dust figure. Here A and C are the hollow branching streaks produced on a somewhat reddish background, D yellowish branches which grow outward from a somewhat yellowish portion at the ends of the branching streaks C, E enveloping margins of the branches D, the inside of which is of a somewhat reddish colour. In the portion between the branches D and the margin E there is nothing. When the electric impulse applied to the electrode is too strong a somewhat yellowish zone B shown in the figure does not occur, and the hollow streaks A can be clearly seen as before. However the grains crowded at the outside of the ends of the stresks C are always of a somewhat yellowish colour; and this seems to be caused, in all probablity, by the attraction of the sulphur due to the positive charge existing at the end of the zone C.

Fig.4



As is stated before, the branches D are yellowish and the inside of the enveloping margin E is reddish. This seems also to be caused by the fact that the negatively charged sulphur in the portion between the branches D and the enveloping margin E is attracted toward the branches D, and that the positively charged red lead in the same portion is repelled away toward the portion E, resulting in the weakening of the electric field in the portion between the branches D and the enveloping margin E as in the case of the negative dust figure.

The resemblance of the appearance of the enveloping margins in the cases of the reversal-like phenomena and the dust-figures, seems to show that both are due to essentially the same cause.

It has already been stated that the presence of ions on the photographic plate at the moment of the impression of the discharge figure, is favourable to the formation of the enveloping margins. Thus

we may assume reasonably, as was suggested by Prof. Yoshida, that many ions are produced on the photographic plate, by being illuminated by the spark simultaneously with the impression of the discharge figure. If so a similar separation of the ions thus produced, as in the case of the dust figures, will occur at the ends of the regular cathode and the irregular anode branches of the discharge figure on the photographic plate; and this will bring forth the weak electric field portion as in the case of the dust-figure, just at the ends of the negative and the positive branches. The ionization by collision of the ions with gas molecules and consequently the light to be emitted by the brush discharge on the surface of the photographic plate, by whose means the discharge figure seems to be impressed, is thus missing at the portion of the weak electric field under consideration; and this will result in the formation of the narrow and dark unaffected portion, on the photographic plate, just at the outer end of the cathode and anode figure. The accumulation of the ions of the same sign as that of the electrode, at the portion just beyond this dark unaffected portion, will make the electric field so strong there as to cause the ionization by collision of ions with gas molecules. The enveloping margin just outside of the dark unaffected portion seems to be formed in such a way.

It seems to the writer that the reversal-like phenomenon is essentially the same both for the cathode and the anode figure. The main difference is in the arrangement of the branches. In the case of the anode figure, this arrangement is very irregular, and most of the branches are so separated from each other that every branch is enveloped separately by the enveloping margins. The arrangement of the cathode branches is so regular, however, that all the branches terminate on a continuous boundary, so that the enveloping margin of every branch is entirely amalgamated to one enveloping only the continuous outer boundary of the terminals of the regular cathode branches. Considering in such a way the reversal-like phenomena of the cathode and the anode figure seem to be understood easily by supposing that many ions are produced directly or indirectly on the photographic plate by its being illuminated with a spark light simultaneously with impression of the discharge figure.

The writer wishes to express his sincere thanks to Professor U. Yoshida of Kyoto Imperial University for his invaluable suggestions.

Plate I

Fig. 1

Fig. 2

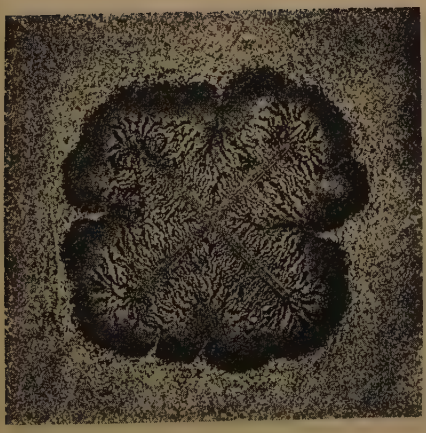


Fig. 3

Fig. 4

On the Favourable Direction of Growth of Some Metal-Crystals

By

Shogo Tsuboi

(Received June 22, 1929)

Abstract

The favourable crystallographic direction of growth of various metal-crystals is examined in the present experiment. Most of the aluminium and lead crystals grow in the direction nearly parallel to the [100] axis of the face-centred cubic crystals of these metals. The majority of the zinc, cadmium and bismuth crystals grow in the direction nearly perpendicular to the principal axis of the hexagonal crystals of these metals.

It is already known from the experiments of P. W. Bridgman[1] and K. Tanaka[2] that when the crystallisation of a molten metal is made to proceed in one direction by cooling it from one end, the direction of growth of the metal crystal assumes a certain definite crystallographic direction. In the present experiment the writer examined the same problem with five different metals. The metal crystals were prepared by Czochralski's method[3]. Thus the direction of growth of the metal crystal is supposed to coincide with the lengthwise direction of the long specimen of the crystal in the present case. The speed at which the wire was hung up from its molten state was limited to about 2—4 cms. per minute. The orientation of the crystallographic axes of the crystal thus obtained was determined by treating the Laue-spots taken with the specimen with the globe and the spherical scale devised by Prof. U. Yoshida.[4]

1 Nature, **117**, 569 (1929).
2 These Memoirs, **11**, 361 (1928).
3 Z. S. Phys. Chem., **92**, 219 (1917).
4 Japanese J. Phys., **4**, 133 (1927).

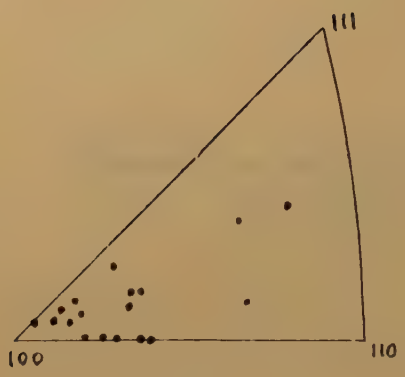


Fig. 1

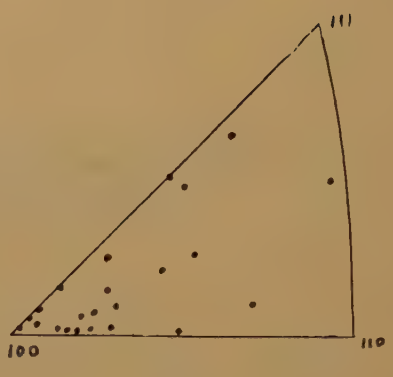


Fig. 2

In Figs. 1 and 2 the dots represent the direction of growth of the aluminium crystals obtained by hanging up aluminium wire solidified from its molten state at the end of polycrystalline wires of copper and iron respectively, where the [100], [110] and [111] axes of the cubic crystal of aluminium are taken as the reference axes of the stereographic projection. It will be seen from these figures that the direction of growth is more favourable in the direction parallel to the [100] axis than in the others, independently of the material of the hanging wires. However when a single crystal of aluminium is used as the hanging wire, the orientation of the crystallographic axes of the crystal newly obtained is found to be the same as that of the hanging crystal.

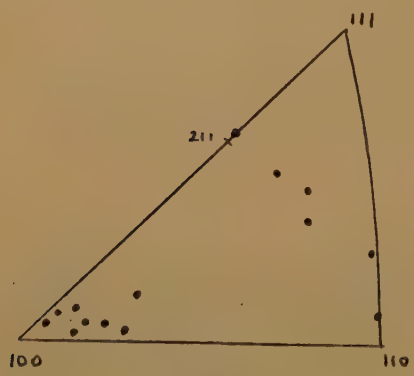


Fig. 3

A similar result is also obtained with the lead crystals. The direction of growth of the lead crystal is represented in Fig. 3, as in the case of the aluminium crystal. However, there were

Fig. 4

several crystals, in this case, which grew in the direction nearly perpendicular to the [111] axis of the cubic crystal. The six dots lying between the [211] and the [110] axes in Fig. 3, represent the direction of growth of such crystals.

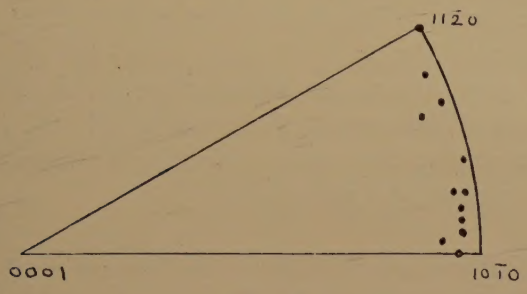


Fig. 5

The dots in Fig. 4 represent the direction of growth of the hexagonal crystal of zinc which is obtained by hanging up the wire of zinc solidified from its molten state at the end of a polycrystalline wire of copper, in reference to the crystallographic axes. Next a single crystal of zinc is used as the hanging wire, and it is found that, if the (0001) plane of the hanging crystal does not incline too much to the direction of growth of the new crystal, a crystal having the same crystallographic orientation as that of the hanging crystal is obtained; and that, if the inclination of the (0001) plane of the hanging crystal to the direction of growth of the new crystal is greater than about 40°, a crystal which grows in the direction nearly parallel to the [10$\bar{1}$0] axis is obtained. Taking these points into consideration, we find that the crystal of zinc seems to grow more easily in the direction parallel to the [10$\bar{1}$0] axis of the hexagonal crystal.

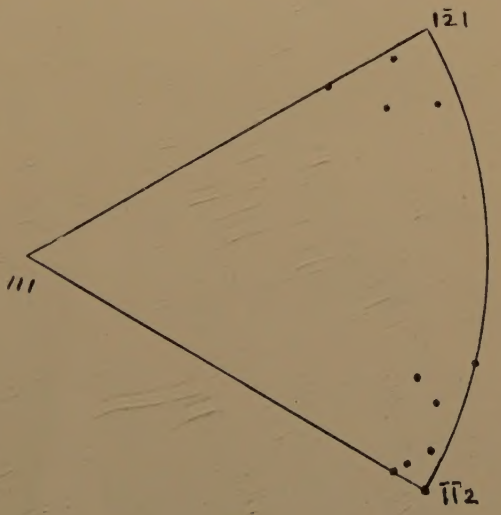


Fig. 6

A similar experiment with cadmium crystals indicates that the hexagonal crystal of cadmium grow evenly in all directions parallel to the basal plane of the hexagonal crystal, because the distribution of the dots in Fig. 5 which represent the direction of growth of the

cadmium crystals in stereographic projection, is wholly at random in the (0001) plane.

The rhombohedral hexagonal crystal of bismuth also grows more easily in the direction nearly perpendicular to the principal axis [111], as in the case of zinc and cadmium. The direction of growth of the crystals of this metal is shown in Fig. 6.

Thus it may be said, from the results stated above, that the favourable direction of growth of the crystal of a metal is definite for each metal, and that this favourable direction is intimately connected with the lattice form of the crystal of a metal.

In conclusion, the writer wishes to express his sincere thanks to Professor U. Yoshida of Kyoto Imperial University for his kind guidance during the research.

Shiga Normal School,
May 9, 1929.

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